

5-2012

# Stratigraphy and Provenance of Shallow Sandstones Endountered in Wells in Townships 9 and 10 North, Ranges 6 and 7 West, White County, Arkansas

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STRATIGRAPHY AND PROVENANCE OF SHALLOW SANDSTONES  
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ENCOUNTERED IN WELLS IN TOWNSHIPS 9 & 10 NORTH, RANGES 6 & 7  
WEST, WHITE COUNTY, ARKANSAS

This thesis is submitted in partial fulfillment  
of the requirements for the degree of  
Master of Science in Geology

By

Lacie Knight  
Arkansas Tech University  
Bachelor of Science in Geology, 2004

May 2012  
University of Arkansas



## **Abstract**

Paleozoic formations in western Arkansas have been well-studied; however, they are not well-understood in the eastern part of the state. The study area encompasses Townships 9. N. and 10. N., Ranges 6. W. and 7. W. in north-central White County, Arkansas. This area is at the intersection of four physiographic provinces as defined by the Arkansas Geologic Survey- the Ozark Plateaus, the Arkansas River Valley, the Ouachita Mountains, and the Mississippi Alluvial Plain. Interpretations of the surface unit in the area disagree. The Arkansas Geologic Map shows that the Morrowan Hale Formation crops out in the area; however, various petroleum geologists suggest that the surface unit in the area is of the Atoka Formation. Several wells in the area have produced natural gas from the sandstones in question, meriting further investigation of the units' potential source.

Petrographic analysis of 17 thin sections prepared from sidewall cores taken from three wells in the study area, correlation of 141 wireline logs, and construction of cross sections, gross sand isopachs, and structure maps were used to develop a stratigraphic framework of the area. These analyses imply that the subject units are likely of the Hale Formation and have multiple sources including the Ouachita Mountains, the Appalachian Mountains, the Ozark Dome, and the North American cratonic interior. Additionally, the sandstones were likely deposited in a transitional near-shore marine environment with a fluvial-deltaic influence.

This thesis is approved for  
Recommendation to the  
Graduate Council

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## **ACKNOWLEDGEMENTS**

Many thanks are due to my committee members. First, I would like to offer my gratitude to my advisor, Dr. Doy Zachry for his persistent encouragement, patience, and guidance throughout this process. Without him, this accomplishment would not have been possible. Also, much appreciation goes to Dr. Walter Manger for teaching me to think outside the box and always consider alternatives to the accepted paradigm. Last but not least, I will be ever-grateful to Doug Melton for his constant guidance, support, and encouragement both in my professional and academic careers. His assistance in reaching this milestone has been invaluable.

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## 1.0 Introduction

Paleozoic formations in western Arkansas are generally well-understood; however, these formations have been inadequately investigated in the eastern part of the state near the boundary between the Paleozoic formations of the Ozark Plateaus and the Arkansas River Valley with the Quaternary deposits of the Mississippian Embayment. According to the Arkansas Geologic Map, the Prairie Grove Member of the Morrowan Hale Formation crops out in the area (Figure 1); however, geological interpretations by various petroleum geologists suggest that the shallowest unit encountered in wells in the area is the Lower Atoka Orr sandstone, a petroleum industry marker.

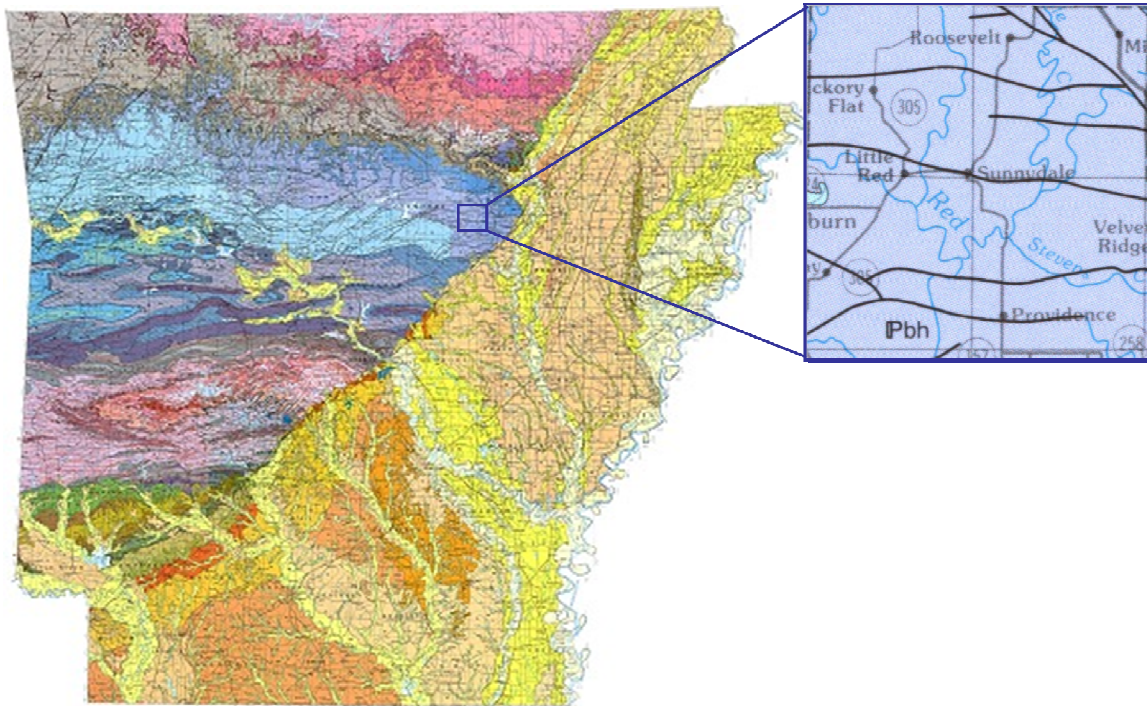


Figure 1: Arkansas Geological Map with the study area highlighted and expanded. (Haley, 1976)



### 1.01 Location

This study analyzed the stratigraphy, mineralogy, and petrography of shallow sandstones encountered in wells in Townships 9.N. and 10. N. and Ranges 6.W. and 7.W. in White County, Arkansas (Figure 2) in order to determine the possible provenance of the sandstones and reconcile differences between industry correlations and the Arkansas Geological Survey surface maps. Shallow wells, which produced initially high volumes of gas from the units in question, merit investigation in order to determine a possible source of the sands as a basis for future investigation.

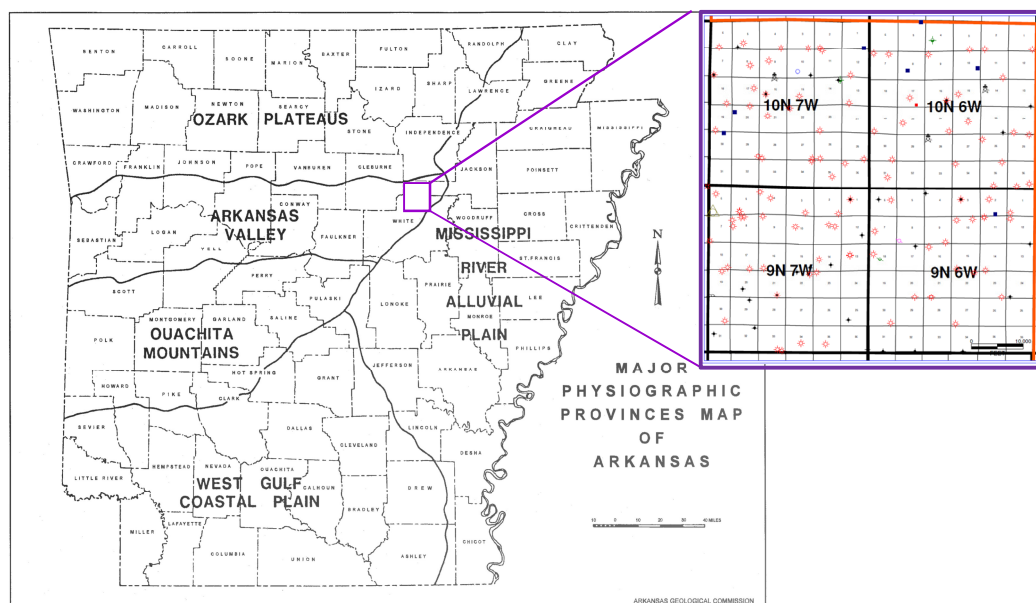


Figure 2: Arkansas Geological Survey county-based Arkansas Physiographic Province Map with the study area highlighted in purple and expanded to show Townships and Ranges of interest and the surface hole location of wells included in the study. (Modified from <http://www.geology.arkansas.gov>)

### 1.02 Type Log

The selected type log for the study is the SEECO, Hefley 09-07 1-12PH. This well was selected due to its central location within the study area. The well lacks faults and includes all of the markers used for the purposes of this study (Figure 3).

SEECO, Inc., HEFLEY 09-07 1-12H  
12-9N-7W  
WHITE COUNTY, AR

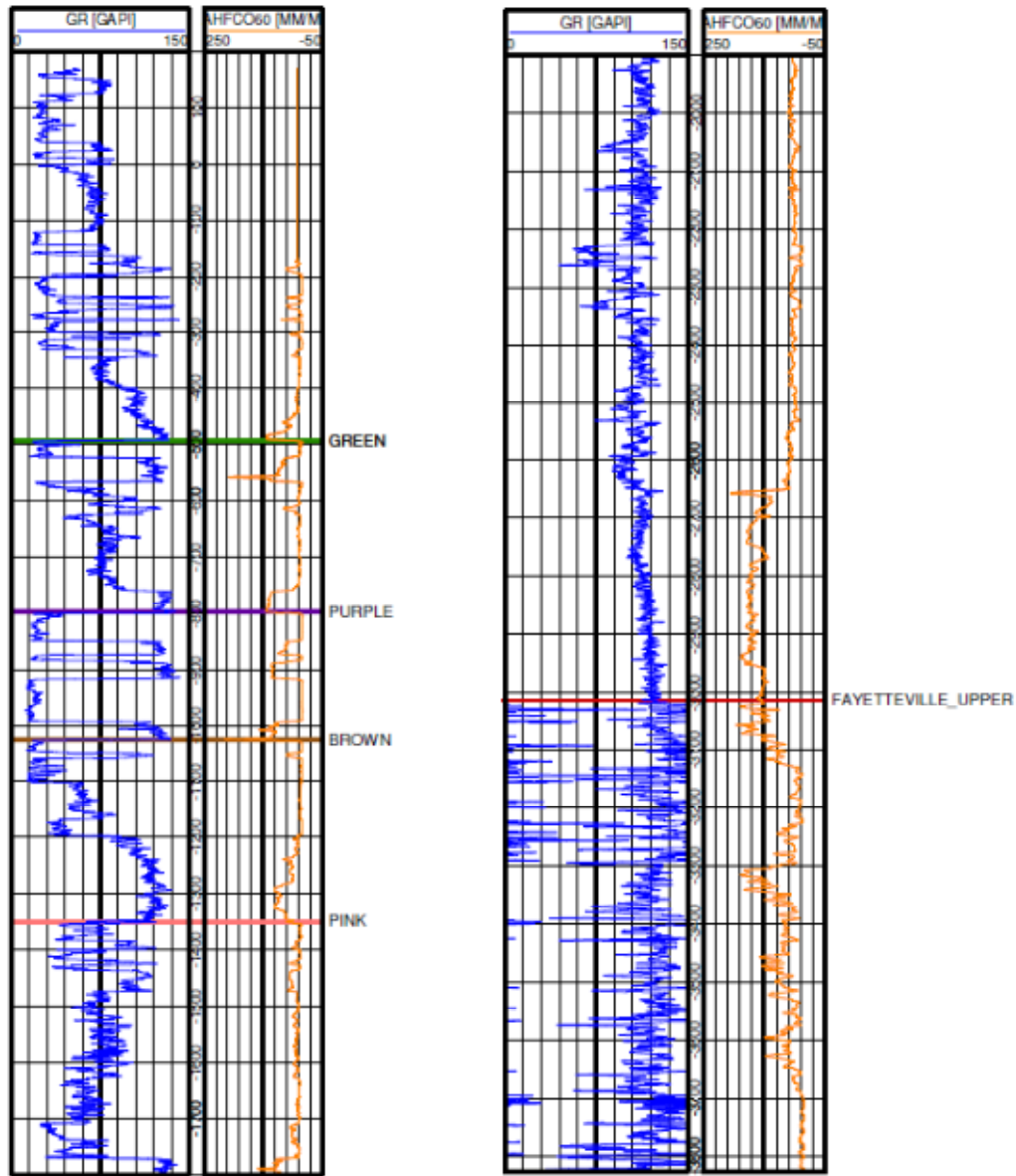


Figure 3: Wireline log from the SEECO, Inc., Hefley 09-07 1-12PH, showing gamma and conductivity curves from 200' SSTVD to 3800' SSTVD. The four markers chosen for the study are shown as well as the top of the Fayetteville Shale for reference.

### 1.03 Methods and Procedures

Petrographic analysis of 17 thin sections prepared from sidewall cores taken from three wells in the study area was conducted for this study. Correlation of wireline logs from 141 wells in the study area was used to establish a stratigraphic framework (Figure 4). Three dipmeter logs were examined for evidence of sediment transport direction. Cross sections, gross sand isopachs, and structure maps were generated to support and supplement the petrographic analysis.

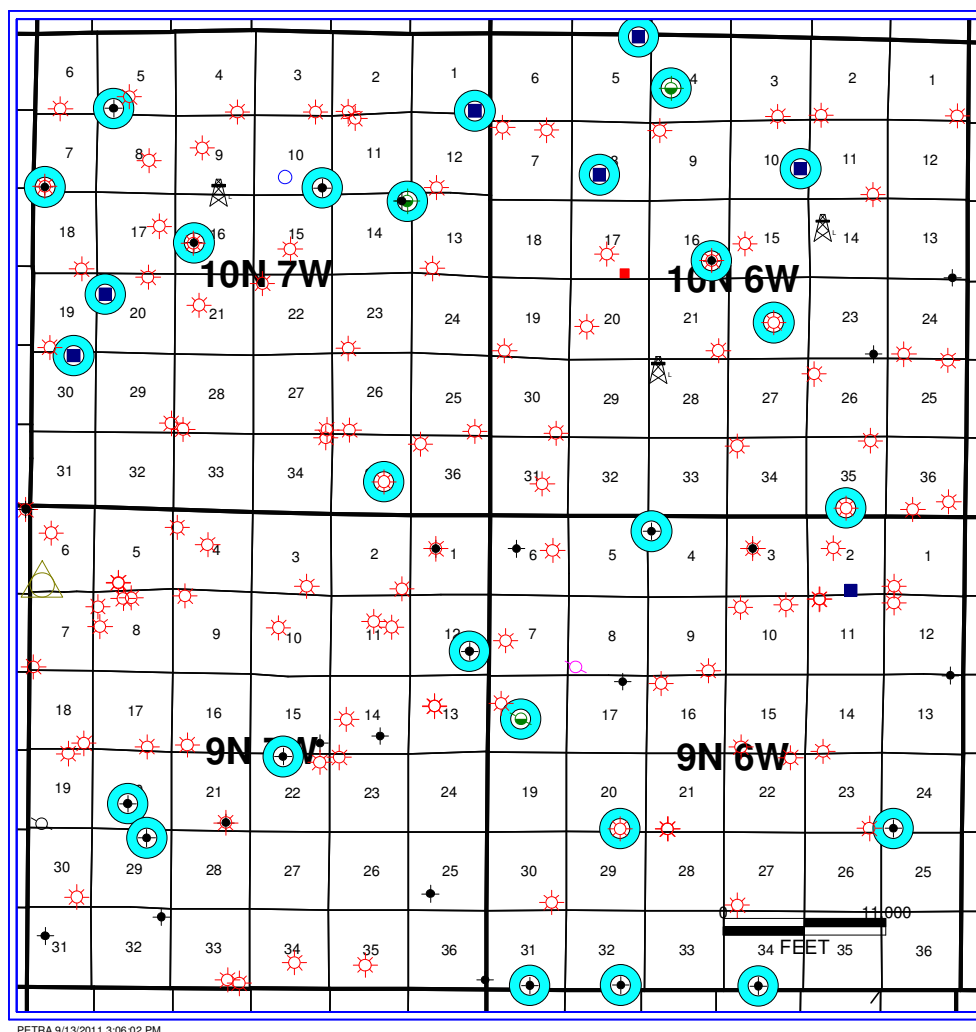


Figure 4: Study area with surface hole locations of the wells included in the study. Wells highlighted in light blue are pilot holes or vertical wells.

## **2.0 Geological Setting**

The study area lies in the northeast corner of the Arkansas River Valley physiographic province near the boundary with the Paleozoic formations of the Ozark Plateaus, Quaternary deposits of the Mississippi River Alluvial Plain, and the Ouachita Mountains to the southwest (Figure 2). The Arkansas River Valley includes a portion of the Arkoma Basin petroleum province and is bounded to the north by the Ozark Plateaus, to the south by the Ouachita Mountains, and to the east by the Mississippi River Alluvial Plain, also known as the Gulf Coastal Plain (Figure 2). Surface formations in this area are assigned to Pennsylvanian sandstone-shale sequences of the Morrowan and Atokan age, with some unconsolidated Quaternary sediments in the area of the Arkansas River.

The Arkoma Basin is a structural trough, which extends westward from the Mississippi River Alluvial Plain into Oklahoma, with a width ranging from 20 to 50 miles (Zachry and Sutherland, 1984). From the Cambrian through the Morrowan, this area was a broad, shallow continental shelf with relatively slow, episodic deposition of carbonates, sand, silt, and shale. There is little thickening from north to south of strata through Morrowan time; however, the deposition rates increased dramatically during the Atokan, with formation thicknesses increasing to the south due to subsidence of the basin resulting from loading of the crust to the south during the Ouachita Orogeny (Houseknecht, 1986).

The Ouachita Mountains rise from beneath a thick cover of Cenozoic strata in central Arkansas, extend into Oklahoma, and reappear in Texas as the Marathons. The Ouachita Orogeny is widely considered to be an extension of the same tectonic event that formed the Appalachians to the east, the formation of Pangea. From Precambrian to early Mississippian, the area was the site of continental rifting and the opening of an ocean basin, resulting in the creation

of an abyssal plain; however, in the earliest Mississippian, the sea began to close from the east to the west due to southward subduction of first oceanic lithosphere followed by what would become the North American continent below Llanoria (Houseknecht and Kacena, 1983). The event culminated in the late Atokan with the Ouachita Orogeny, resulting from a southward island arc or continental mass or possibly both in succession colliding with the North American continent.

The Ozark Plateaus, comprised from south to north of the Boston Mountains Plateau, the Springfield Plateau, and the Salem Plateau are part of a larger geologic feature known more broadly as the Ozark Dome. Precambrian granite and rhyolite, which crop out in the St. Francois Mountains of southeastern Missouri, are at the core of the uplift (Figure 5). This area was alternately subaerially exposed and submerged continental slope during the many transgressions and regressions of the Paleozoic, resulting in limestone accumulations and sandstone/shale sequences with several unconformities, the most prominent of which is the erosional surface which marks the Mississippian/Pennsylvanian boundary.

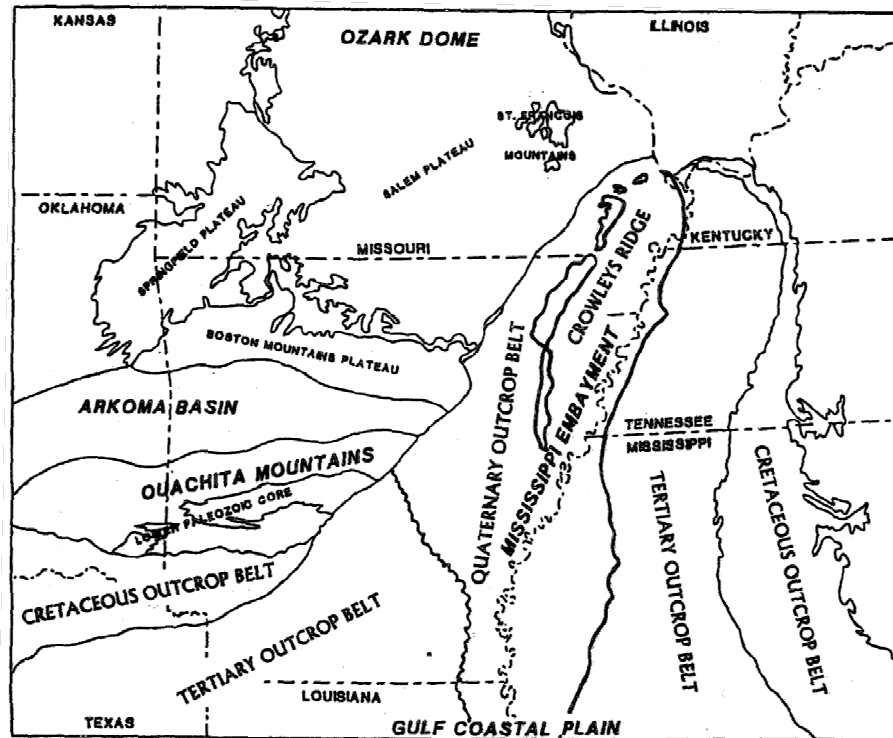


Figure 5: Figure showing the geologic provinces of Arkansas, Boston Mountains Plateau, Springfield Plateau, Salem Plateau, St. Francois Mountains, and other adjacent features. (Manger, 2009, from Manger, Zachry, and Garrigan, 1988)

## 2.01 Tectonic Evolution

During the Precambrian, uplift resulted in the formation of the Ozark Dome, followed by rifting along the southern margin of the North American continent and the creation of an ocean basin to the south in the late Precambrian and early Paleozoic (Figure 6A). At this point, the southern margin of North America developed into a passive margin, including the classic continental shelf-slope-rise geometry, similar to the modern Atlantic margin of North America, with the shelf in the area of the southern Ozark Dome and Arkoma Basin and the slope and rise in the southern Arkoma Basin and northern Ouachita Mountains (Figure 6B). The majority of the strata forming what are now the Ouachita Mountains were deposited in the abyssal plane.

This passive margin setting characterized the area until the Devonian. During the late Devonian or early Mississippian and into the Atokan in the middle Pennsylvanian, the ocean basin slowly closed (Figure 6C and 6D). Convergence began as southward subduction of oceanic crust below a southern land mass, either an island arc system or continent known as “Llanoria”, evidenced by volcanic detritus present in Ouachita deposits and encountered in the subsurface near the Sabine uplift in southern Arkansas, south of the Ouachitas. Several kilometers of flysch were also deposited during this event in the remnant ocean basin.

By the early Atokan, the ocean basin had been completely subducted, and the southern landmass was actively colliding with the North American continent (Figure 6E). This event resulted in flexure, creating normal, south-dipping faults, which offset basement rocks and allowed growth of Atokan deposits across the faults. By the late Atokan into the Desmoinesian, collision of the subduction complex and southern landmass with the North American continent was complete, resulting in the Ouachita Mountains and a surface structure similar to present day with the Ouachita Mountains to the south, the Ozark Dome to the north, and the Arkoma Basin separating the two (Houseknecht and Kacena, 1983).

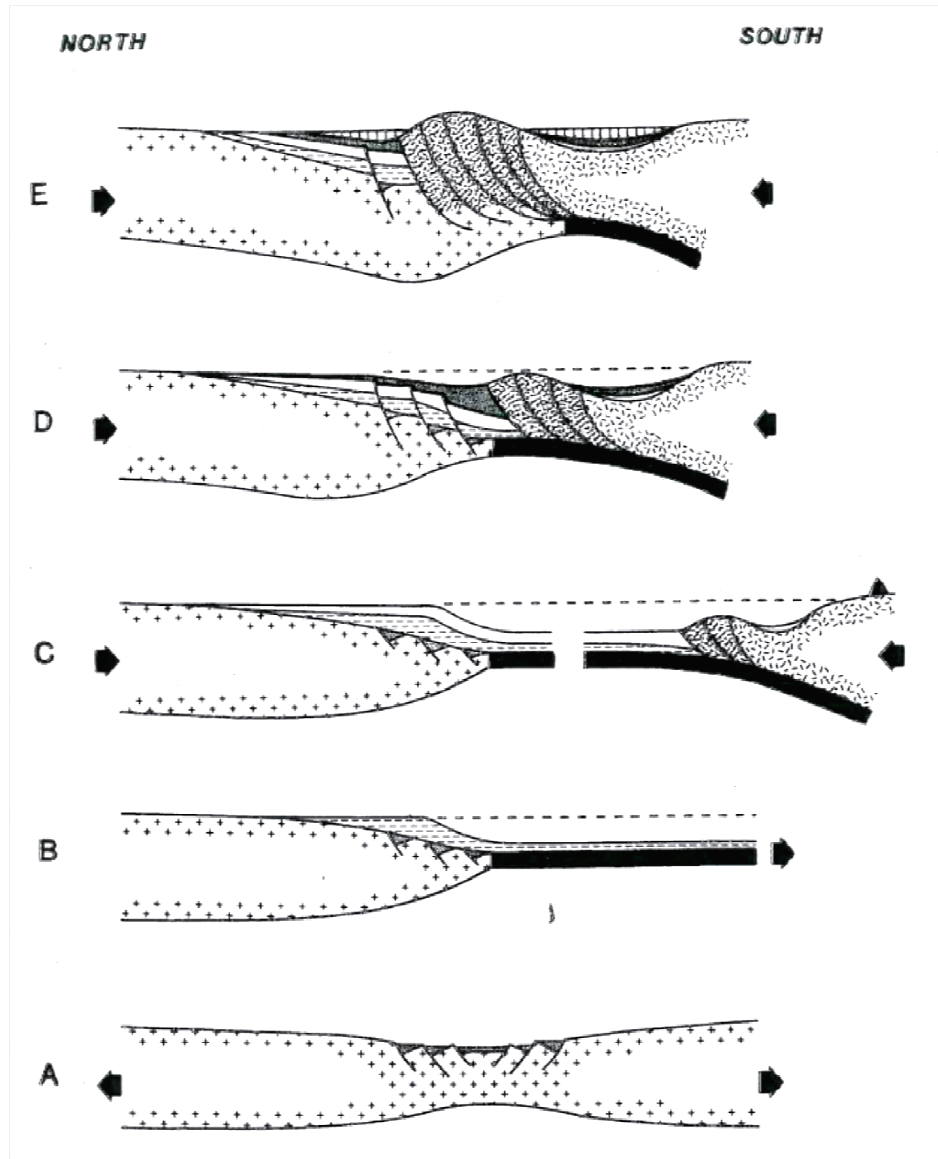


Figure 6: Tectonic evolution of the southern margin of North America. (Houseknecht, 1986)

- A. Late Precambrian-earliest Paleozoic
- B. Late Cambrian-earliest Mississippian
- C. Early Mississippian-earliest Atokan
- D. Early Atokan-middle Atokan
- E. Late Atokan-Desmoinesian



### 3.0 Previous Studies

Morrowan and Atokan formations in and near their type locales along with associated depositional and tectonic histories of the area have been thoroughly studied and described in numerous theses, papers, and publications including, but not limited to, Henbest (1953), Liner (1977), Zachry (1979), Zachry (1983), Houseknecht and Kacena (1983), Zachry and Sutherland (1984), Houseknecht (1986), Sutherland (1988), VanArsdale and Schweig III (1990), Woolsey (2004), McFarland (2004), and Manger (2009). Conversely, investigations of the formations near the eastern extent of their surface exposures have been neglected, and there is a resulting deficit of literature describing the units in the area.

Jimmy T. Vest produced a thesis in 1962 that investigated the surface stratigraphy in the Greers Ferry Reservoir area before completion of the dam at Heber Springs caused inundation of the outcrops. The fossil localities for the thesis were all within 10 miles to 50 miles west of the current study. Primarily through the application of biostratigraphy, he concluded that the surface unit in the area is of Morrowan age, rather than Atokan as previously thought. Lithologic correlation was considered highly questionable for the area, because

“... rocks in the Greers Ferry Reservoir area... have undergone marked lateral changes in lithologic character in relatively short distances. The change in the lithologic character is probably influenced to a great extent by the proximity of the strand line to the reservoir area during deposition of the Paleozoic rocks. Because the nature of the sediments change extensively in the area and because there appears to be little comparison of lithology between Morrowan rocks of the reservoir area and those of northwest Arkansas, it is believed that stratigraphic correlation of the reservoir rocks can only be accomplished through a study of the fossil assemblage and the application of the information to the problem,” (Vest, 1962).

#### **4.0 Lithostratigraphy**

Surface exposures in the study area are of Pennsylvanian age; however, some debate has existed as to whether those exposures are of the Atoka Formation or the Hale Formations. According to the Arkansas Geologic Map (Haley and others, 1976), the Prairie Grove Member of the Morrowan Hale Formation crops out in the area, but geological interpretations by various geologists suggest that the shallowest unit encountered in wells in the area is the Orr sandstone, a regionally continuous sandstone marker within the lower Atoka Formation, which overlies the Brentwood, a generally sandy limestone unit within the Bloyd Formation in the area, which in turn overlies the Hale Formation (Figure 7). Additionally, it is important to note that the Pitkin Formation is not present in the study area, thus the Hale Formation directly overlies the Mississippian Fayetteville Formation, which was used as a reference for correlations in this study and is currently producing natural gas.

An early study in the area (Caplin, 1954) stated that outcrops in the Greers Ferry Reservoir area are of Atokan age, but the Vest thesis proved through biostratigraphy that the exposures are of Morrowan age. Type localities for the Atoka Formation and the Hale Formation are from Atoka County, Oklahoma and Washington County, Arkansas, respectively, long distances west of the White County wells; therefore, stratigraphic variations due to distance and facies changes are expected and have been noted, not only on a regional scale, but also locally (Vest, 1962).

Period	Ozarks	Ouachitas
CARBONIFEROUS	PENNSYLVANIAN	Boggy
		Savanna
		McAlester
		Hartshorne
	Atoka	Atoka
	Bloyd	Johns Valley
	Hale	Jackfork
	Prairie Grove	
	Cane Hill	
	MISSISSIPPIAN	Stanley
	(Imo)	
	Pitkin	
	Fayetteville	
	Batesville	
	(Ruddell)	
	Moorefield	
	Boone	
	St. Joe	Arkansas
		Novaculite (part)

Figure 7: Stratigraphic column illustrating the interval of interest. (McFarland, 2004)

The Atoka Formation, which includes the Orr sandstone, is generally a marine sequence of tan to gray, silty sandstones and grayish-black shales with rare calcareous beds and siliceous shales. The unit contains fossil plants, invertebrate fossils, and trace fossils. In some areas, it also contains coal and coaly shale or pebble conglomerates (McFarland, 2004). Along the northern periphery of the Arkoma Basin, the Atoka Formation is 300 ft. to 500 ft. thick (Zachry and Sutherland, 1984) and reaches an exposed thickness of approximately 25,000 ft. south of the study area in the Ouachita Mountains.

The Hale Formation consists of two members in its type area; an upper member, the Prairie Grove, and a lower member, the Cane Hill. The Prairie Grove Member consists of thin to massive, light to dark gray to dark brown, limy sandstone or sandy limestone, is often crossbedded and may contain lenses of highly fossiliferous, crinoidal limestone and oolitic

limestone and typically lacks shale. The unit contains fragmental fossils of crinoids, bryozoans, brachiopods, algae, coral, trilobites, mollusks, and microfossils (McFarland, 2004).

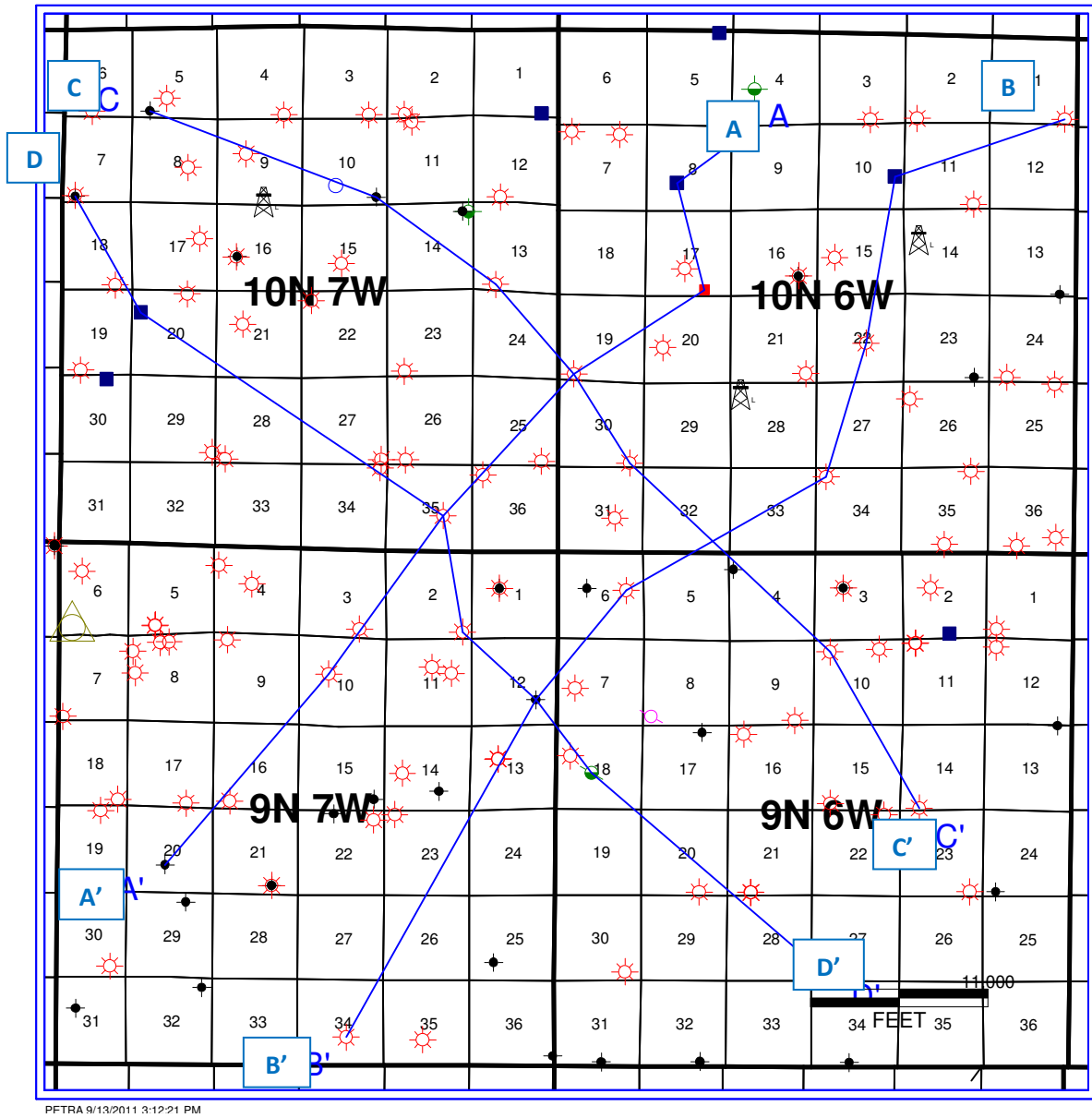
The Cane Hill Member is usually composed of dark gray, silty shale interbedded with siltstone and thinly bedded, fine-grained sandstone that may be calcareous. Occasional thick to massively bedded, noncalcareous sandstones also occur. Mollusks, brachiopods, and other fossils are associated with the calcareous units. According to the Arkansas Geological Survey, the lower contact of the Cane Hill Member marks the Pennsylvanian/Mississippian unconformity (<http://www.geology.arkansas.gov/>).

Four markers were used for the purposes of this study. Though the Vest thesis and the state geologic map (Haley and others, 1976) indicate that it is likely that surface exposures are of Morrowan age, some uncertainty still exists surrounding the age of surface formations, and therefore also the subsurface formations, in the immediate study area; therefore, the markers were labeled green, purple, brown, and pink, from youngest to oldest. The Upper Fayetteville marker is also displayed for reference purposes. The markers were picked from the conductivity curve when it was available and from the gamma curve in cases where no conductivity curve was available.

Four cross sections were constructed. A map of the study area displaying the four cross section lines is included for geographic reference (Figure 8). Two cross sections are along lines from northeast to southwest (Figures 9 and 10), and two from northwest to southeast (Figures 11 and 12). The first two cross sections, A to A' and B to B' show a dramatic thickening trend from northeast to southwest across the study area. Much of this thickening occurs across faults. Additionally, gross sand isopachs were generated for the green, purple, and brown intervals. A gross sand isopach was not created for the pink interval, because the base of this interval is the

Upper Fayetteville, and the Morrowan section between the top of the pink interval and the Upper Fayetteville Shale is highly variable and includes discontinuous sandstones and limestones.

Dipmeter logs for the SEECO, Nicholson 10-06 1-16H; SEECO, Byrd 09-07 3-13; and SEECO, Johnson 10-07 1-16H were examined in addition to the correlation of other wireline logs. The dipmeter data were inconclusive in regard to predominant sediment transport direction. Reprocessing of the data with greater resolution may reveal further insight into the subject; however, that is beyond the scope of this project.



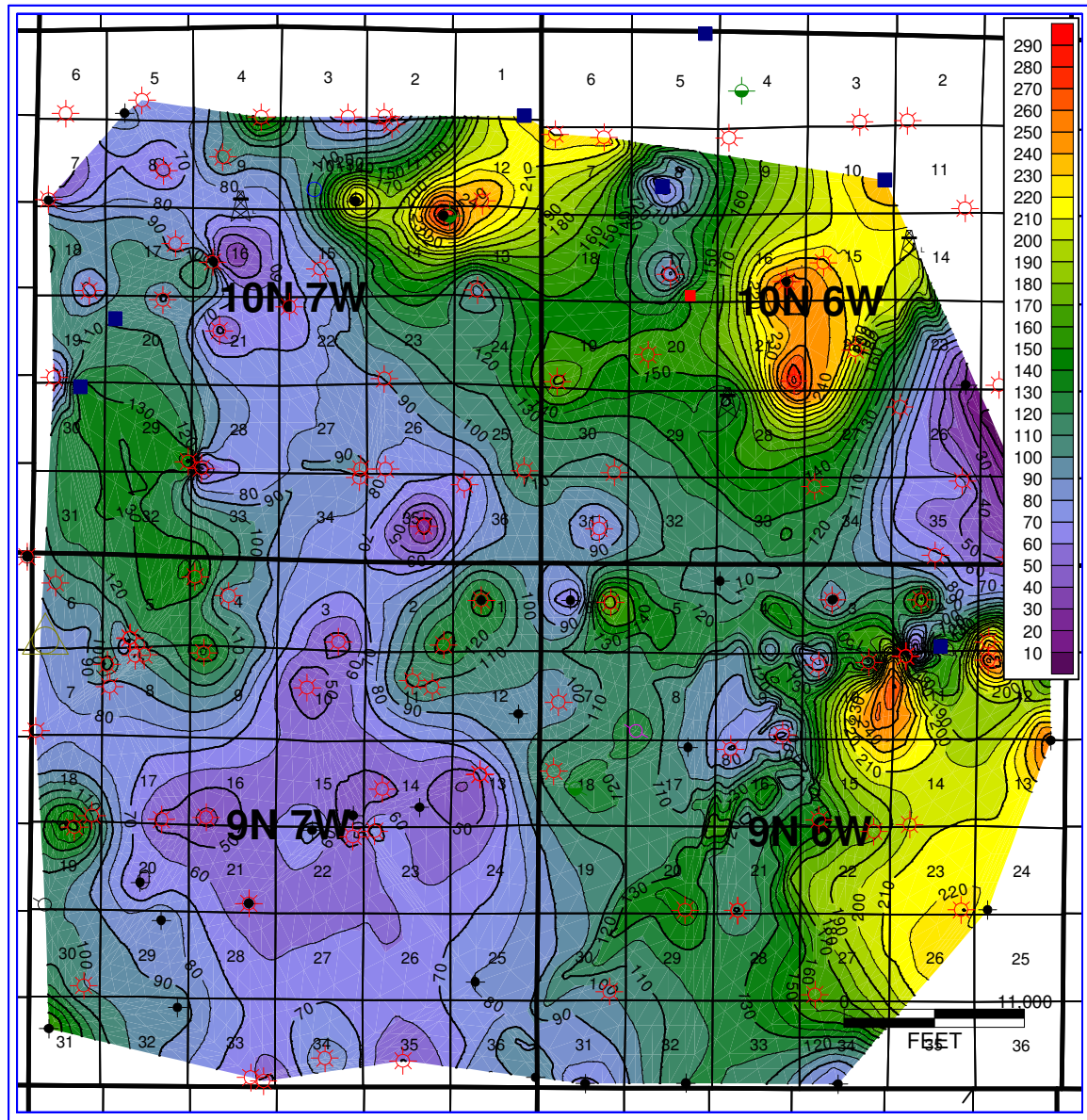












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Figure 13: Gross sand isopach for the green interval. Cooler colors indicate less sand, and hotter colors indicate more sand.



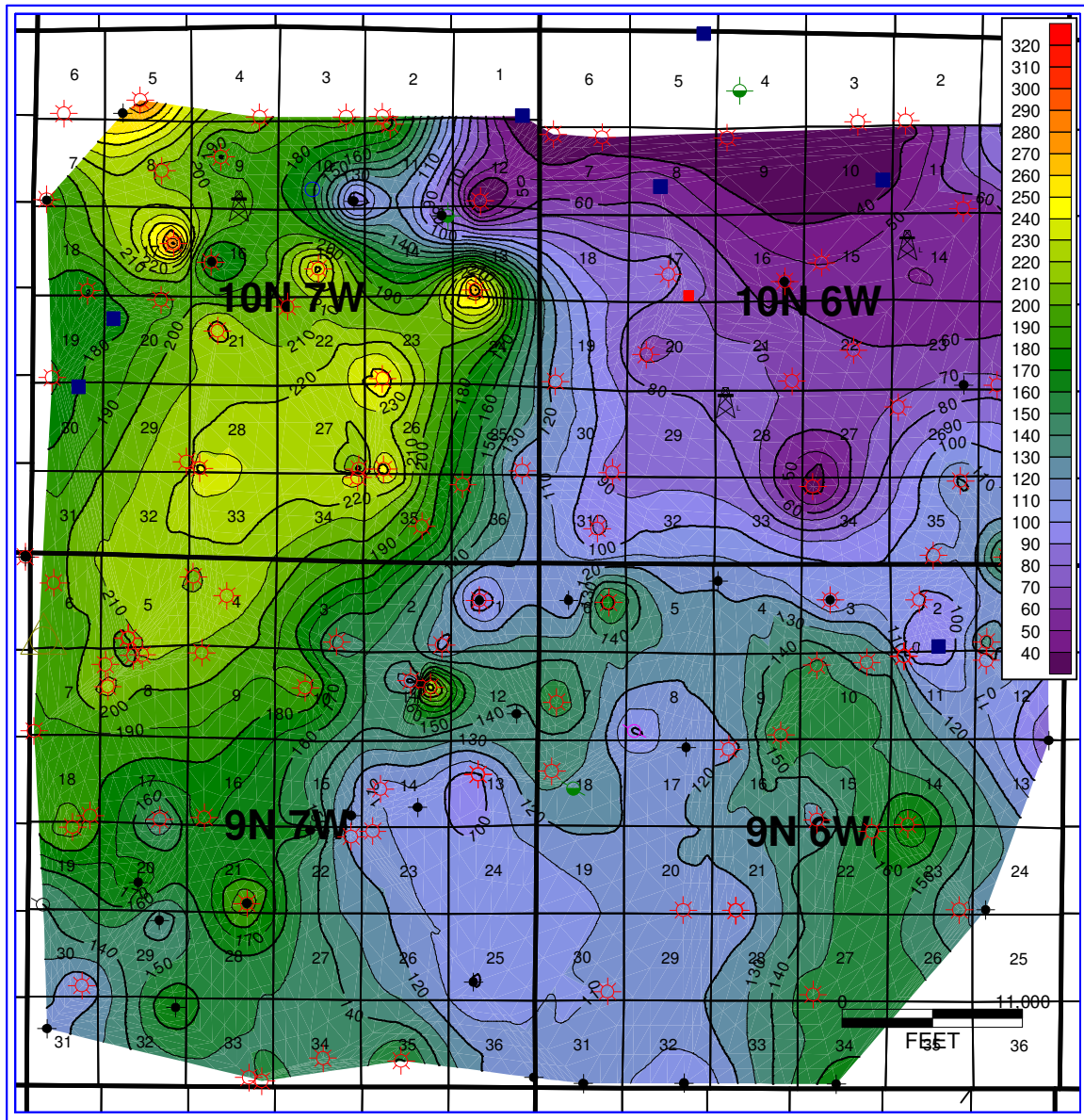


Figure 14: Gross sand isopach for the purple interval. Cooler colors indicate less sand, and hotter colors indicate more sand.

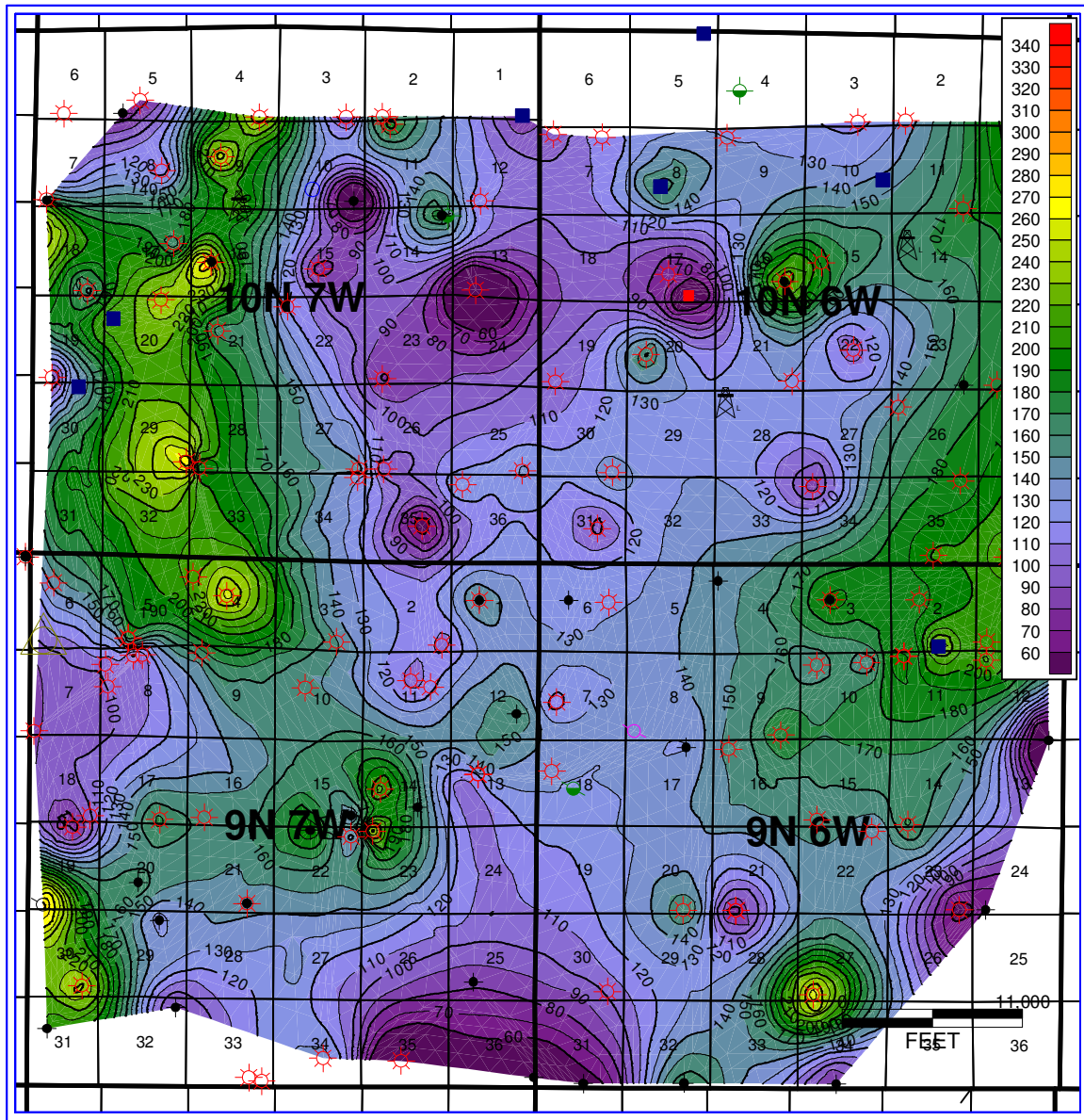


Figure 15: Gross sand isopach for the brown interval. Cooler colors indicate less sand, and hotter colors indicate more sand.

## 5.0 Petrography

Seventeen thin sections were examined for this study. The thin sections were taken from rotary sidewall cores from shallow sands encountered in three wells: the Byrd 09-07 3-13, the Johnson 10-07 2-16, and the Turley 09-07 2-05. The sidewall cores were impregnated with epoxy and were stained for carbonate but not for feldspar. 300 points were counted for each thin section (Figure 17). The numbers of grains, excluding monocrystalline quartz, are displayed in a chart for visualization purposes (Figure 18). The proportions of quartz, lithic fragments, and feldspar were normalized for each in order to compile a Folk Ternary Diagram (Folk, 1974) for purposes of analyzing composition (Figure 19) and a Dickinson Ternary Diagram (1979) to analyze the tectonic setting at the time of deposition (Figure 20). The diagrams were created with the intention of attempting to determine the possible provenance of the sandstones in question. Wireline logs with rotary sidewall core points marked are provided (Figure 21).

### 5.01 Folk Sandstone Classification

For the purpose of compositional analysis of the sandstones in question, quartz, feldspar, and lithic fragment ratios were normalized from the 300 points counted for each of the 17 analyzed thin sections. Monocrystalline quartz and polycrystalline quartz were both included at the quartz pole. All feldspars were included in the feldspar classification. Sedimentary, metamorphic, and volcanic rock fragments were included in the lithic fragments category. All cements, porosity, fossil fragments, overgrowths, and accessory minerals were excluded.

Plotting the data on the Folk sandstone classification triangle shows that the data are clustered toward the quartz end of the triangle, with all samples containing between 87% and 99% quartz. The remainders of the samples are composed of 0% to 9% lithic fragments and 0% to 11% feldspar. Seven samples plotted in the quartzarenite range (Figure 22), five plotted in the

sublitharenite range, four in the subarkose range, and one data point on the line between subarkose and sublitharenite (Figure 22).

### 5.02 Tectonic Depositional Setting

In 1979, William R. Dickinson and Christopher A. Suczek devised a scheme to relate sandstone composition to tectonic setting and provenance. This scheme is similar to Folk's sandstone classification in that quartz, feldspar, and lithic fragments ratios from a sample are normalized and plotted on a ternary diagram; however, polycrystalline quartz is grouped with lithic fragments for this method, and the resulting plot shows the tectonic setting from which the sediments were derived (Figure 23).

Nine of the seventeen data points plotted in the cratonic interior portion of the plot, seven points plotted in the quartzose recycled area of the plot, and one point plotted in the transitional recycled area. Samples plotted in the cratonic interior area of the diagram have high quartz content with minor amounts of feldspar and lithic fragments. These sediments are considered to be highly mature, indicating that the source was from a stable craton and that the sediments may have traveled a long distance and were exposed to intense weathering before deposition.

Those data plotted in the recycled area of the plot are also dominantly composed of quartz but contain a more significant amount of lithic fragments, mostly polycrystalline quartz, than those rocks derived from a cratonic source. Sediments of recycled orogenic provenance are produced by the erosion of uplifted, potentially folded and/or faulted sedimentary and/or metasedimentary rocks. Orogenic provinces are further classified as subduction complexes, collision orogen, or foreland uplift (Dickinson and Suczek, 1979). The apparent source for the portion of the samples plotted in the recycled section for this study is a foreland uplift. A foreland uplift or fold-thrust belt, such as the Ouachita front, may block sediment influx to a

foreland basin, such as the Arkoma Basin, from associated magmatic arcs or suture belts. This provenance provides for characteristically quartz-rich, feldspar-poor sandstones, which resemble and are sometimes indistinguishable from a cratonic source, indicating that some points plotted in the cratonic provenance section have potential of having also been sourced from a foreland uplift.

### 5.03 Observations

Abundant quartz cement and dust rims were noted on many grains, including depths 1487' TVD, 1463' TVD, 1315' TVD, and 1265' TVD from the Byrd 09-07 3-13; 1026' TVD from the Johnson 10-07 2-16; and 1695' TVD from the Turley 09-07 2-05. The abundant dust rims suggest that cementation occurred at least partially within the vadose zone, which implies that the paleoshoreline was south of the study area at some point after deposition. This is consistent with the tectonic history of the area.

Patterns were observed in the Byrd 09-07 3-13 in relation to both the Folk and Dickinson classifications. For the Folk classification (Figure 21), from the deepest sample to the shallowest, the three deepest samples, depths 1539' TVD, 1487' TVD, 1463' TVD, are all within the green marker and are also subarkosic. Depths 1325' TVD and 1315' TVD are within the purple marker and plot as quartzarenite. Depths 1265' TVD, 1192' TVD, and 1185' TVD are also within the purple marker and plot as sublitharenite.

For the Dickinson classification (Figure 23), the pattern is even more obvious within the samples from the Byrd 09-07 3-13. The deepest sample, depth 1539' TVD, plotted within the transitional recycled area of the plot with a significant portion of lithic fragments and some feldspar. Depths 1487' TVD and 1463' TVD have a cratonic interior source and include a lesser amount of lithic fragments along with a decreasing portion of feldspar. Depths 1325' TVD and



1315' TVD also have a cratonic interior source, but no feldspar was observed. The shallower samples, depths 1265' TVD, 1192' TVD, and 1185' TVD, also contain no feldspar but include increasing amounts of lithic fragments from deep to shallow and plot in the quartzose recycled area of the plot. The symbols used for points plotted for figures 19, 20, and 21 are listed in the following table.

Well	Depth	Symbol
Byrd 09-07 3-13		
	1185	✦
	1192	✦
	1265	✦
	1315	✦
	1325	✦
	1463	✦
	1487	✦
	1539	✦
Johnson 10-07 2-16		
	1026	●
	1290	●
	1712	●
	1806	●
Turley 09-07 2-05		
	1549	▲
	1681	▲
	1689	▲
	1695	▲
	1805	▲

Figure 16: Table of well and depth sample symbols used for subsequent figures.

Well Name	TVD (feet)	Quartz- Monocrystalline	Quartz- Polycrystalline	Rock Fragment- Sedimentary	Rock Fragment- Metamorphic	Feldspar	Cement- Quartz	Cement- Calcite	Fossil Fragment	Porosity	Clay	Ferroine Calcite	Zircon	Total
Turley 09-07 2-05	1549	214	16	2	1	1	53	1	1	11	0	0	0	300
	1681	204	14	14	4	6	35	6	0	11	2	4	0	300
	1689	204	31	3	4	8	22	11	0	17	0	0	0	300
	1695	203	20	15	1	3	7	16	0	32	3	0	0	300
	1805	254	26	4	1	1	6	0	0	0	8	0	0	300
Johnson 10- 07 2-16	1026	206	23	1	0	4	18	2	0	41	5	0	0	300
	1290	222	7	1	4	28	11	3	4	19	1	0	0	300
	1712	204	45	1	4	1	29	6	0	4	1	5	0	300
	1806	264	4	2	0	0	29	1	0	0	0	0	0	300
Byrd 09-07 3- 13	1185	202	30	12	11	0	25	0	1	18	1	0	0	300
	1192	200	30	14	0	0	14	8	14	15	2	2	1	300
	1265	203	16	14	3	0	21	6	10	19	5	3	0	300
	1315	227	9	3	0	0	20	5	9	19	2	5	1	300
	1325	218	8	3	1	0	7	1	0	54	5	0	0	300
	1463	243	8	2	8	5	27	0	0	6	1	0	0	300
	1487	202	12	0	2	21	7	4	0	36	15	0	1	300
	1539	133	97	12	17	17	15	4	0	5	1	0	0	300

Figure 17: Table showing data from 300 point counts for the 17 thin sections.

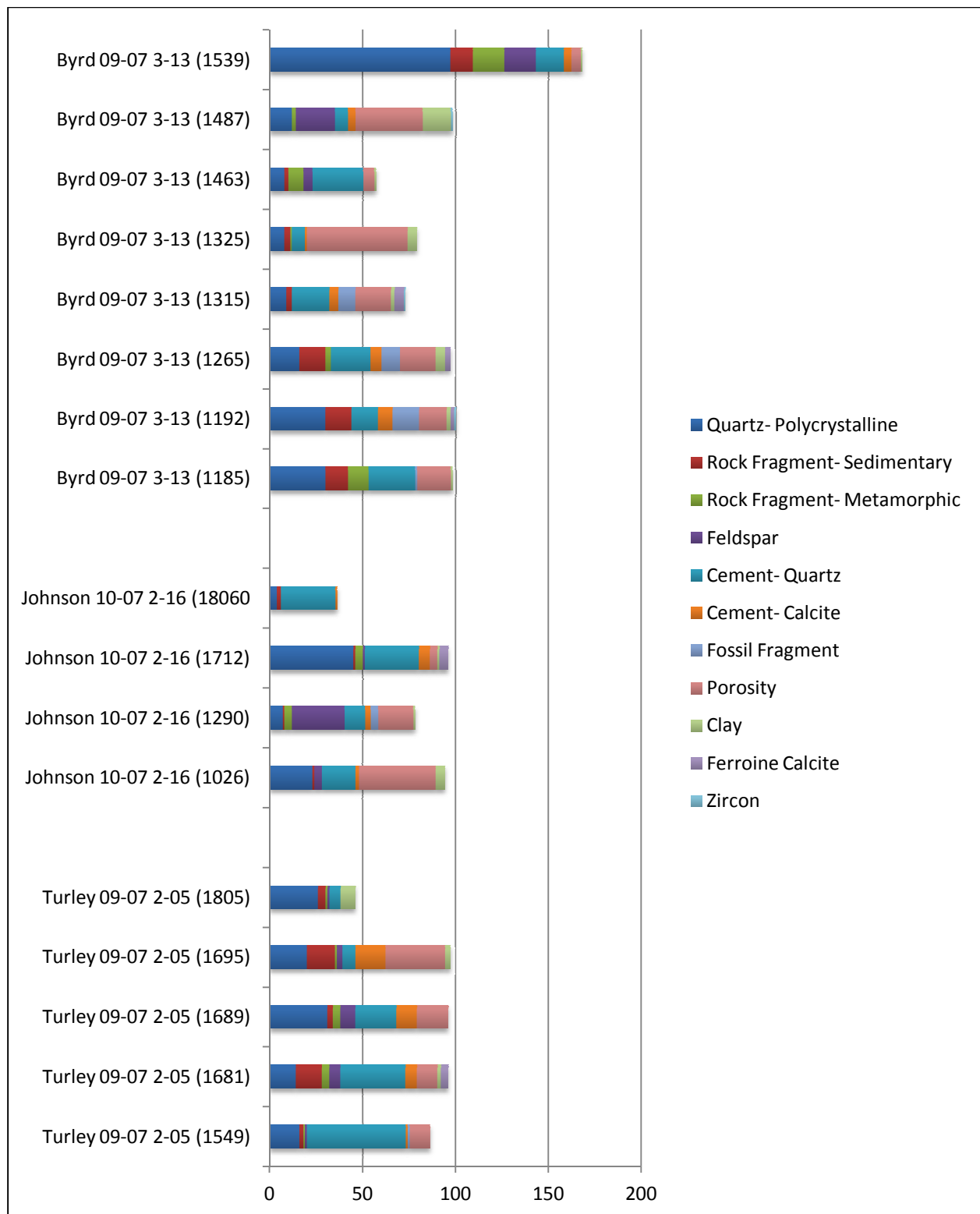


Figure 18: Chart comparing the number of grains, excluding monocrystalline quartz, for each of the 17 thin section samples.

Well Name	TVD Depth (feet)	Quartz (%)	Feldspar (%)	Lithic Fragments (%)
<b>Turley 09-07 2-05</b>	1549	99	0	1
	1681	91	2	7
	1689	94	3	3
	1695	92	1	7
	1805	98	0	2
<b>Johnson 10-07 2-16</b>	1026	98	2	0
	1290	87	11	2
	1712	98	0	2
	1806	99	0	1
<b>Byrd 09-07 3-13</b>	1185	91	0	9
	1192	94	0	6
	1265	93	0	7
	1315	99	0	1
	1325	98	0	2
	1463	94	2	4
	1487	90	9	1
	1539	83	6	11

Figure 19: Table of normalized data for the Folk classification system. Quartz includes both polycrystalline and monocrystalline quartz. Lithic fragments include metamorphic and sedimentary rock fragments.

Well Name	TVD Depth (feet)	Quartz (%)	Feldspar (%)	Lithic Fragments (%)
<b>Turley 09-07 2-05</b>	1549	91	0	9
	1681	85	2	13
	1689	82	3	15
	1695	84	1	15
	1805	89	0	11
<b>Johnson 10-07 2-16</b>	1026	88	2	10
	1290	85	11	4
	1712	80	0	20
	1806	98	0	2
<b>Byrd 09-07 3-13</b>	1185	79	0	21
	1192	82	0	18
	1265	86	0	14
	1315	95	0	5
	1325	95	0	5
	1463	91	2	4
	1487	85	9	6
	1539	48	6	46

Figure 20: Normalized quartz, feldspar, and lithic fragment data for the Dickinson classification system. Quartz includes only Monocrystalline quartz. Lithic fragments include sedimentary rock fragments, metamorphic rock fragments, and polycrystalline quartz.

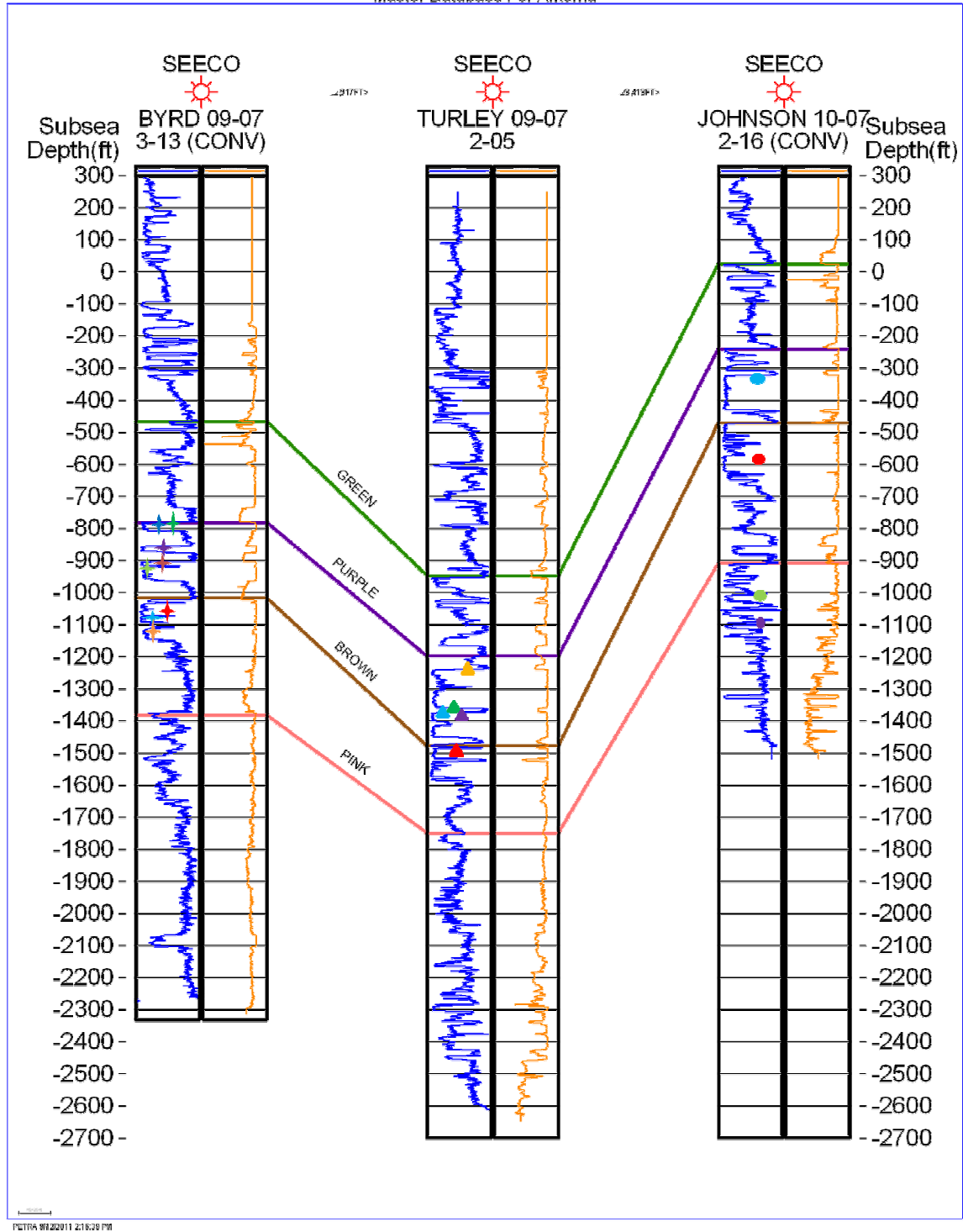


Figure 21: North to south cross section of the three wells from which thin sections were taken. Depths are in subsea true vertical depth. Sample symbols are as indicated in the preceding table.

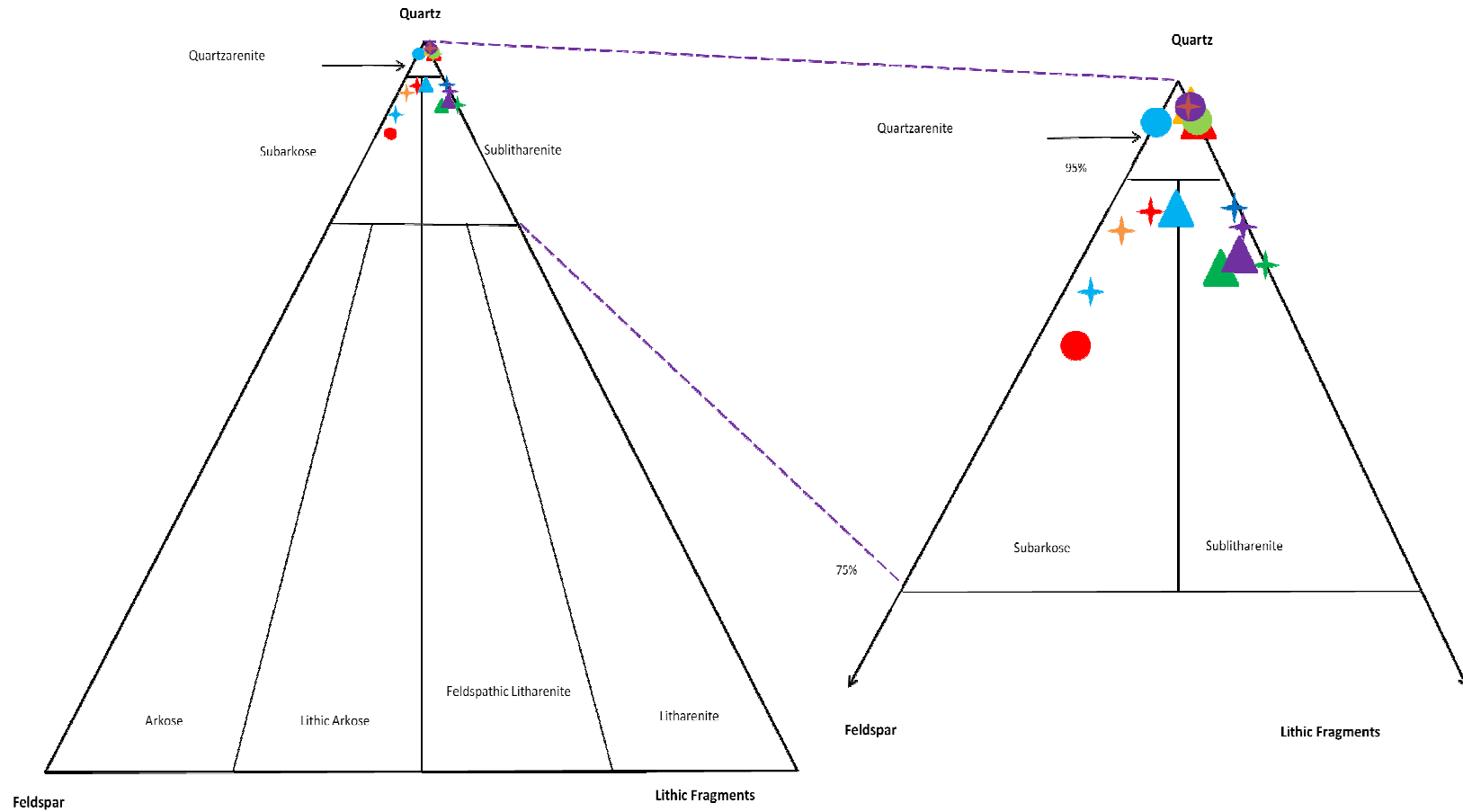


Figure 22: QFL (Quartz, Feldspar, Lithic Fragment) sandstone classification ternary plot after Folk, 1974. The plot on the left is the entire diagram. The top of the triangle is expanded on the right due to clustering of the data toward the quartz end of the plot.

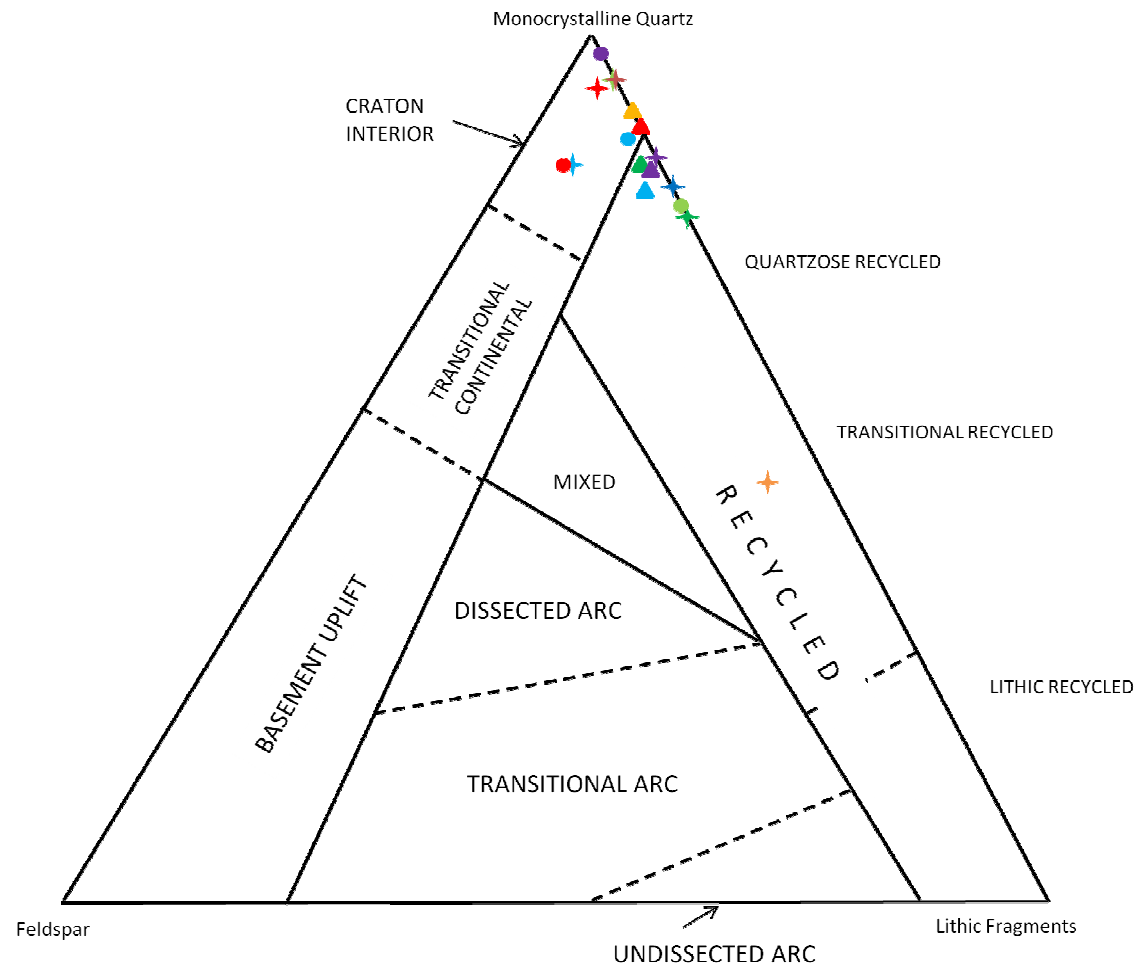


Figure 23: QmFLt (Monocrystalline Quartz, Feldspar, Lithic Fragments) triangle after Dickinson and Suczek, 1979. Normalized point count data from 17 thin sections are plotted as per the table on the previous page.



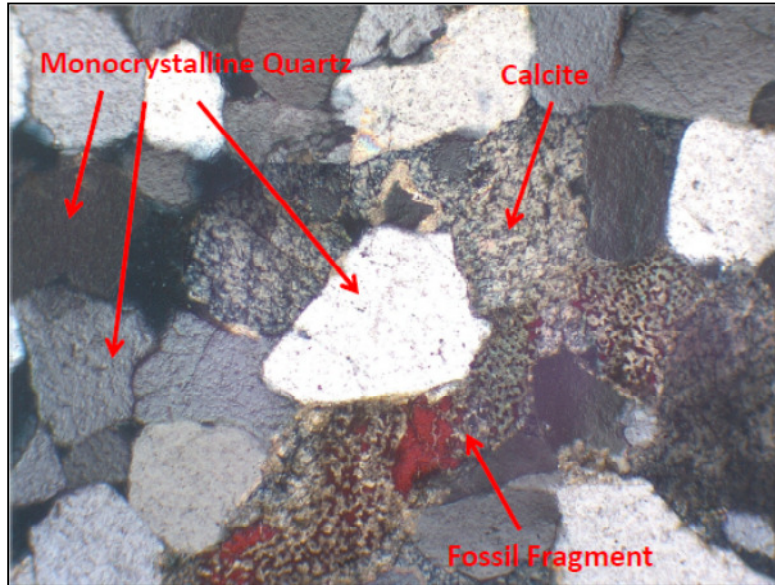


Figure 24: Example of a quartzarenite from the Byrd 09-07 3-13 at 1315' TVD. This photomicrograph was taken at 10x magnification. Monocrystalline quartz, which is the main component of this sample, calcite, and a fossil fragment are noted.

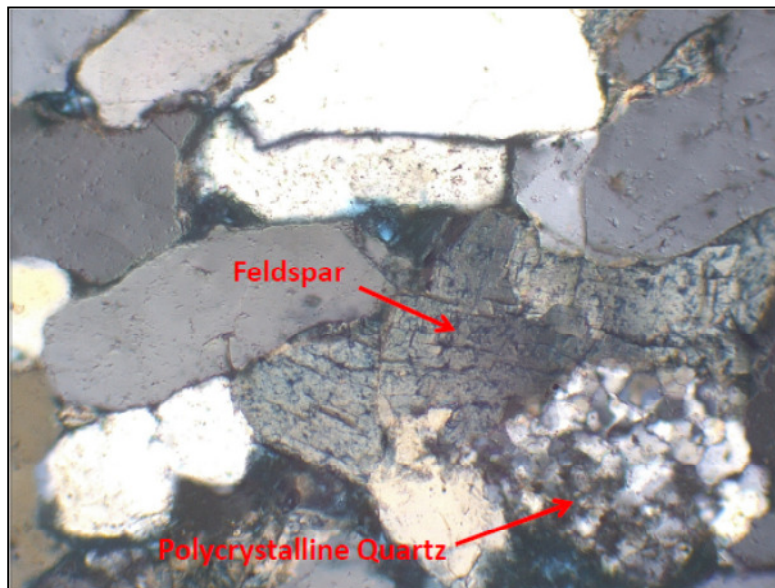


Figure 25: Example of a subarkose from the Turley 09-07 2-05 at 1689' TVD. This photomicrograph was taken at 10x magnification. Feldspar, which is a significant portion of subarkosic sandstones, and polycrystalline quartz are noted. Several grains of monocrystalline quartz are also visible.

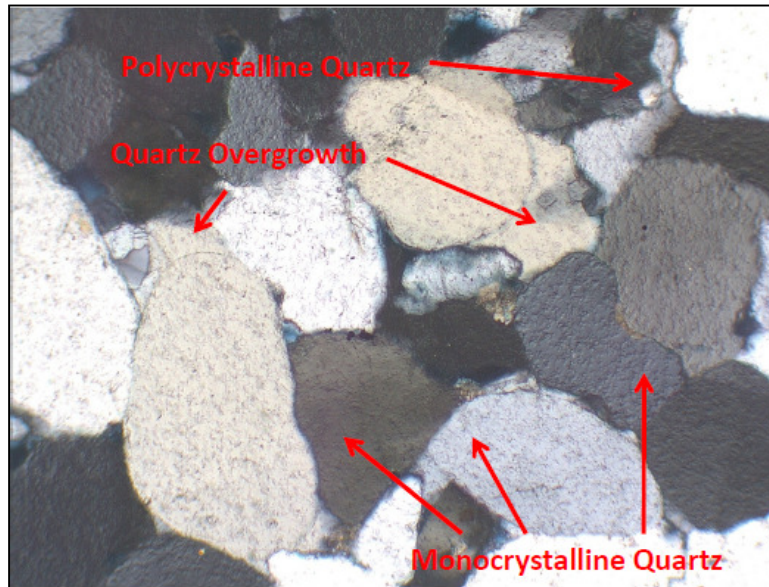


Figure 26: Example of a sandstone sourced from a cratonic interior tectonic setting from the Byrd 09-07 3-13 at 1463' TVD. This photomicrograph was taken at 10x magnification. Many monocrystalline quartz grains are visible along with on polycrystalline quartz grain and quartz overgrowths.

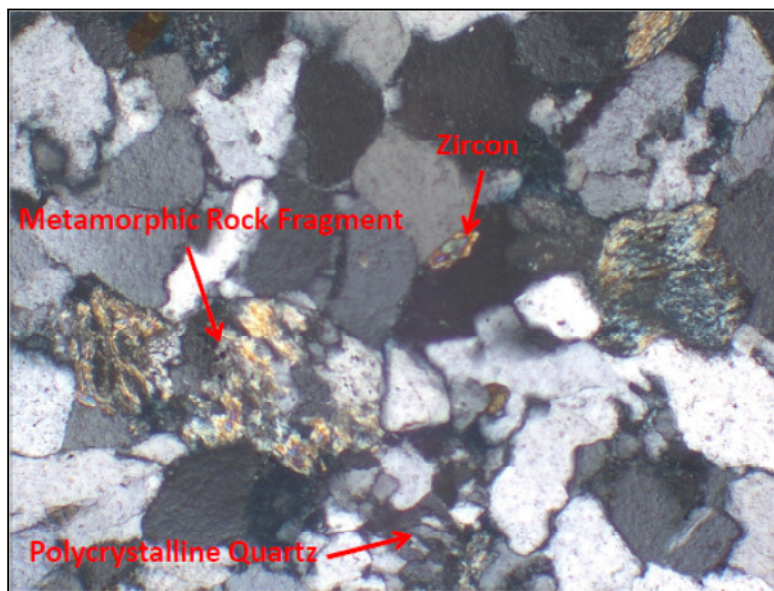


Figure 27: Example of a sandstone sourced from a transitional recycled tectonic setting from the Byrd 09-07 3-13H 1539' TVD. This photomicrograph was taken at 10x magnification. Several Monocrystalline quartz grains are visible. Polycrystalline quartz and a metamorphic rock fragment, both grouped in the lithic fragments category of the Dickinson classification scheme, as well as a zircon grain are noted.

## 6.0 Conclusions

- The sandstones in question are likely of the Hale Formation.
- The Dickinson plot strongly implies multiple sediment sources for the sandstones.

Probable sediment sources include the Ouachitas to the south, the Appalachians to the east, the Ozark Dome, and the North American cratonic interior. Analysis of dipmeter logs did not provide convincing evidence to support a single sediment transport direction.

- Abundant dust rims on quartz grains indicate that the stratigraphic section was within the vadose zone for some period of time post-deposition.
- The depositional environment of the sands is likely dominantly near-shore marine and includes a fluvial-deltaic component.
- Large, angular plagioclase grains indicated in analyses of other samples from the area were not noted in the samples used for this study. Large, angular plagioclase grains indicate a nearby source. The nearest possible source of feldspar is currently the St. Francois Mountains on the southeastern flank of the Ozark Uplift to the north of the study area (Figure 7).

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